DIFFUSION WELDING OF STRUCTURAL COMPONENTS FOR AERONAUTICS AND ASTRONAUTICS

K. Gerber

Translation of "Zum Diffusionsschweissen von Bauteilen fuer die Luft-und Raumfahrt," Raumfahrtforschung, Vol. 18, Jan. - Feb. 1974, pp. 38-41

(NASA-TT-F-15866) DIFFUSION WELDING OF STRUCTURAL COMPONENTS FOR AERONAUTICS AND ASTRONAUTICS (Techtran Corp.) 10 p HC $4.00 CSCL 13H
N74-31950
Unclas
G3/15 47758

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
WASHINGTON, D. C. 20546 AUGUST 1974

STANDARD TITLE PAGE

1. Report No. NASA TT F-15,866	2. Government Accession No.	3. Recipient's Catalog No.
4. Title and Subtitle DIFFUSION WELDING OF STRUCTURAL COMPONENTS FOR AERONAUTICS AND ASTRONAUTICS		5. Report Date August 1974
		6. Performing Organization Code
7. Author(s) K. Gerber		8. Performing Organization Report No.
		10. Work Unit No.
9. Performing Organization Name and Address Techtran Corporation P.O. Box 729, Glen Burnie, Md. 21061		11. Contract or Grant No. NASW-2485
		13. Type of Report and Period Covered Translation
12. Sponsoring Agency Name and Address National Aeronautics and Space Administration Washington, D. C. 20546		14. Sponsoring Agency Code

15. Supplementary Notes

Translation of "Zum Diffusionsschweissen von Bauteilen fuer die Luft-und Raumfahrt," Raumfahrtforschung, Vol. 18, Jan. - Feb. 1974, pp. 38-41

16. Abstract

Diffusion welding as a modern technique for the fabrication of sandwich structures and integral plates with high thermal and mechanical loads is especially well suited for the requirements of special aerospace products. The report presents the results of tests with diffusion-welded models made from aluminum, titanium and steel alloys. Finally the fabrication of some structure elements is described.

17. Key Words (Selected by Author(s))	18. Distribution Statement Unclassified - Unlimited

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages	22. Price
Unclassified	Unclassified	8	

DIFFUSION WELDING OF STRUCTURAL COMPONENTS FOR AERONAUTICS AND ASTRONAUTICS

K. Gerber[1]

1. Introduction

The high mechanical and thermal requirements of component parts for aeronautics and astronautics have lead to the development of construction methods which demand the introduction of modern welding techniques, for instance, diffusion welding. Sandwich structure and integral plates are considered at the moment the best structural units for laminate construction because they can be produced and welded together more easily than most others. The welding temperature is, however, limited by the welded material's tolerance for heat. On the other hand, it is possible with diffusion welding to attain the strength and heat tolerance of the basic material. /38*

In the United States and the Soviet Union, the diffusion welding process is already being used in production. In Germany, on the other hand, it has hardly gotten beyond the research stage. In the Dornier-system company they have been working with the diffusion welding process since 1968. Their research up till now has been conducted with the goal of checking the practical applicability of this welding method for structural component parts for aeronautics and astronautics.

2. Diffusion Welding Process

In diffusion welding the substances to be welded are pressed together and are heated for a certain time in a vacuum or in the presence of an inert gas. Temperatures applied in this process are approximately two-thirds of the melting temperature of the material to be joined. The welding of the joined parts is effected by a crystalline growth on the contact surfaces of the two masses, due to the diffusion of the individual atoms.

Diffusion welding offers several advantages in contrast to other welding methods. Because there are no liquid phases in this process, there is little

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[1]Dornier-System Company, Friedrichshafen

*Numbers in the margin indicate pagination in the foreign text.

change in the joint structure. As a result of the operational temperatures, which are low in comparison to other welding techniques, and since it is possible to allow a long cooling off period, very little inner stress occurs. Reducing the dangerous stress also produces good dimensional stability and very little distortion. Using diffusion welding, it is very easy to weld component parts while maintaining very narrow tolerance limits. It is also possible, if necessary, to join component parts with complicated surfaces and to do so at places which would be inaccessible to normal welding techniques. Other advantages of diffusion welding are the elimination of sebsequent work on the welded seam, the possibility of welding different materials, and the welded joint's high resistance to corrosion.

3. Diffusion Welding Equipment

The diffusion welding equipment of the Dornier-system company is displayed in Figure 1. The equipment is designed for diffusion welding under vacuum conditions, but the equipment can also be used for processes which employ over-pressure in the presence of a protective gas.

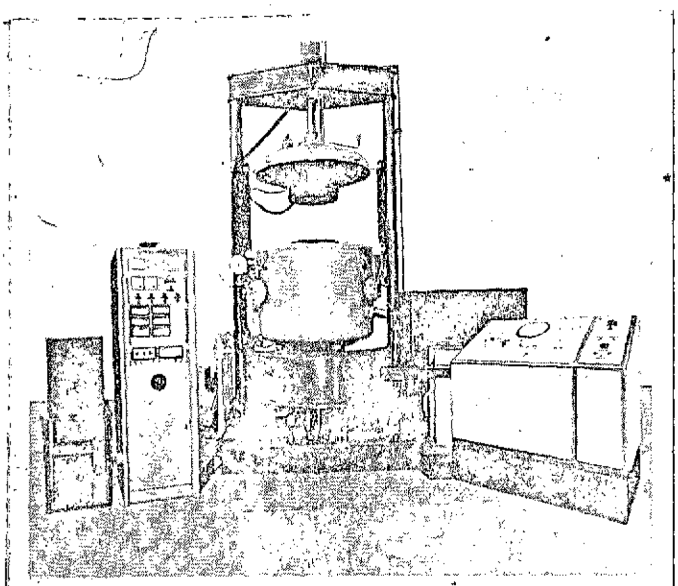

Figure 1: Diffusion Welding Equipment with a Vacuum Chamber and a Hydraulic Press, Along with Control Equipment.

The necessary welding temperature is attained by heating the entire chamber with electrical coils. The heating equipment is set up for a temperature range of between 100° C and 1300° C. The material is /39 compressed on a cylindrical hydraulic press by two vertically arrayed plungers. To open the press, the upper plunger with the press top is raised. The compression force is between two and 20 kilodynes (220,000 kiloponds). The depressurization equipment consists of a pump which is designed to work in the pressure range between 760 and 10^5 Torr.

The pump itself consists of an oil diffusion pump fitted with a vapor seal, a pressure piston, and a cutoff pump. The oven itself is so designed that workpieces up to 500 millimeters across and 300 millimeters high can be accommodated in the equipment. The welding is done in a zone of constant temperature which is 500 millimeters across and 200 millimeters high. This 200 millimeter space is in the center of the oven. In order to maintain continual watch over the welding parameters, the equipment has been provided with a polygraph device which records the temperature, pressure and vacuum as a function of time when welding is being done. The equipment is programmed to allow cost-effective equipment operation, and to keep servicing problems to a minimum.

4. Determining the Welding Parameters of Different Materials

By now welding parameters have been determined for such materials as are used in aeronautics and astronautics: alumiunum, titanium and steel alloys. Internal layers have been joined directly, and various disparate materials have also been successfully welded.

The samples to be welded had a diameter of 6 millimeters and were 50 millimeters long. Each time, 4 different diffusion weld samples were produced at once. Evaluation of the welded joint was determined by

- static joint strength tests
- structural tests
- hardness tests
- corrosion tests.

The results of the strength tests are shown in Figure 2, 3, and 4. For the strength tests, the welded joint was not reworked after it was finished.

No one has yet been able to attain a welding factor of 1 because of the insoluble oxide which acted as a diffusion barrier. The welding factor is, in this case, the quotient of the joint strength of the welding model to the joint strength of the basic material after welding. The best values for the welding factor of aluminum alloys were approximately 0.63. By using cushion layers which can dissolve previously impenetrable covering layers, the "weld-ability" can be improved even more. With the steel and titanium alloys which were tested, welding factors of 1 were achieved in the static joint strength tests.

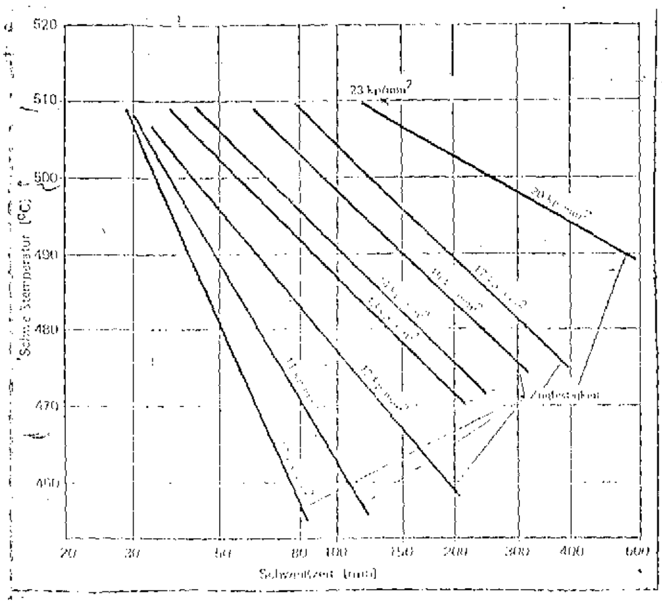

Figure 2: Influence of Length of Time and Temperature of Welding on the Tensile Strength of the Welded AlCuMg2 Models; Pressure Applied: $P = 5\ N/mm^2$ (0.5 kiloponds/mm^2); Processing of the Faces: Finely Lathed and Mechanically Polished: Tensile Strength of the Basic Material After Welding: $358\ N/mm^2$ (36.5 kiloponds/mm^2).

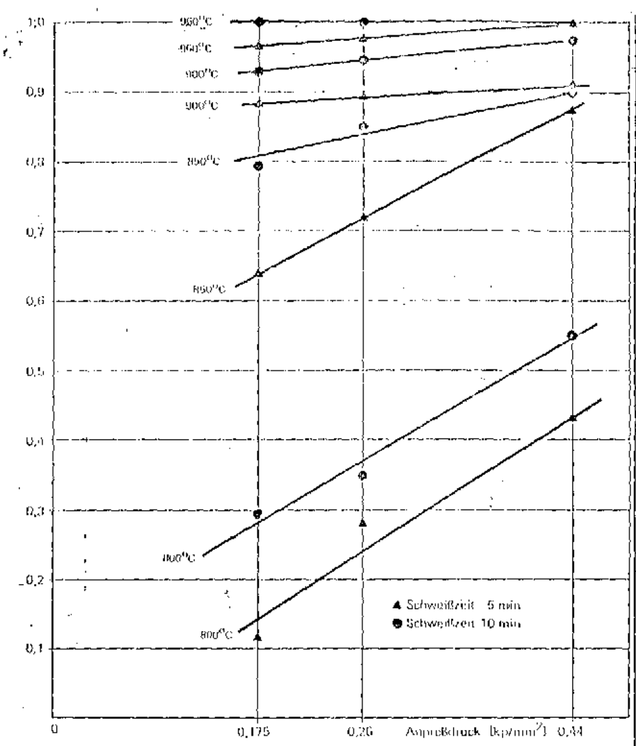

Figure 3: Influence of the Welding Parameters on the Welding Factor in Test Welding of TiAl6V4.

5. Production of Structural Elements /40

After the optimal welding parameters had been determined using the models, several typical component parts were produced using diffusion welding (Figures 5 - 9).

Evaluation of welded joints is made by using mechanical and technological testing methods by which the tensile or shearing strength can be ascertained.

Tensile strength of the welded seam was also determined in those component parts so structured that the individual stress lines of the component parts could be worked upon.

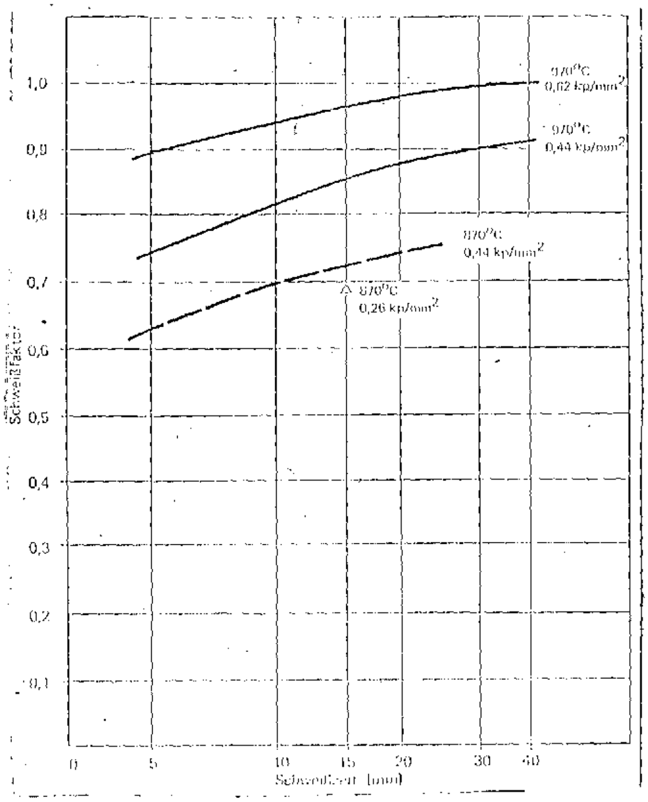

Figure 4: Influence of the Welding Parameters on the Welding Factor in Welding Tests of Chrome-Molybdenum-Vanadium-Hardened Steel.

To ascertain the shearing strength of the welded joint, component parts were used out of which flexible bars could be cut. These flexible bars were put under such strain that when they broke, the attendant shearing forces, with respect to the metal-failure hypothesis, was greater at the joined parts than the maximum concomitant bending strain at the edge of the cross section.

No data could be assembled on the strength of large-surface welded joints on sheet parts, because no definitive maximum strain test processes could be brought to bear on such component parts, and because non-destructive testing methods on such diffusion welded joints as yet have been able to provide either no data or very limited data about the possible limits of error.

A welding factor of only 0.7 to 0.9 could be ascertained for the structural elements on which destructive welded joint tests were made, even though the conditions were exactly the same as those which provided a welding factor of 1 in the welding jobs done to determine the optimal parameters. The cause of this has not yet been fully explained. This phenomenon could, however, be regarded as due to the differing compression factors in small welding models and large scale component parts when the same pressure is applied. The reason for the differing compression factors can be regarded as the dependency of the compression factor, aside from that of the pressure itself and of the working material, on the form of the model and on the friction between the piston and /41 the material. A small amount of compression in welding component parts can deter enlarging of the cotangent welding surfaces by reducing the rough edges, and especially be breaking down layers which act as diffusion barrers.

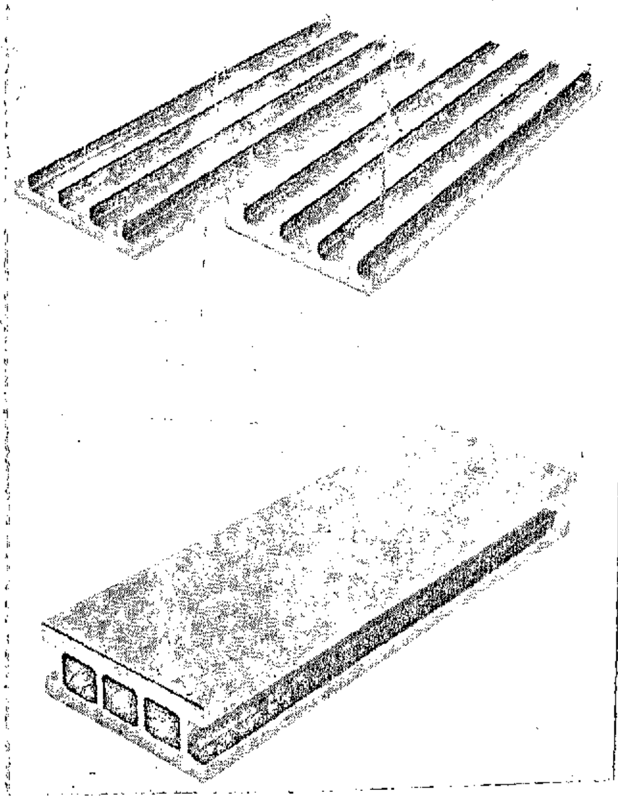

Figure 5: Integral Plate of Chrome-Molybdenum-Vanadium-Hardened Steel-Before and After Welding.

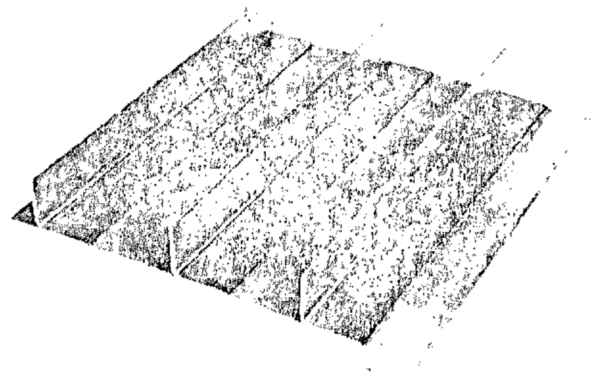

Figure 6: Perpendicularly-Aligned Sheet-Metal of TiA16V4.

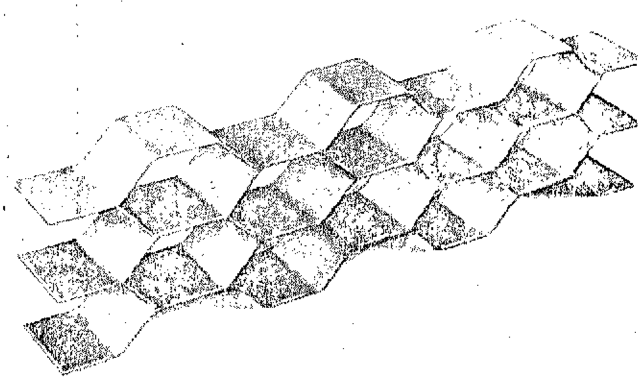

Figure 7: Diffusion-Welded Honeycomb of TiA16V4, 0.075 mm Thick.

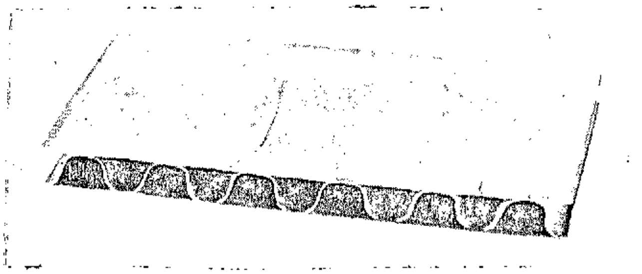

Figure 8: Diffusion-Welded Sandwich Plate-Core is TiV13Cr11A13 - 0.13 mm Thick; Cover Plate is TiA16V4 - 0.3 mm Thick.

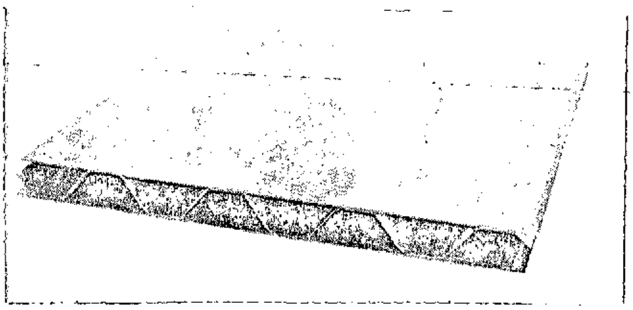

Figure 9: Sandwich Plate with Center in Trapezoid Form Made of Hardened Steel Allog 1,7734.4.

6. Summary - Outlook

From the work done up till now, it is clear that diffusion welding demonstrates advantages in certain application when compared to other welding methods in a technological and operational sense. There is a demonstrable applicability of the results obtained in welding tests to uses in manufacturing components parts. More research is necessary to further upgrade the welding factors obtained to date in making components parts. Future work should be done on non-destructive testing of diffusion welded joints so that the process will have prospects for large-scale use. In addition, processes should be developed for diffusion welding of parts without using vacuum chambers to escape the size requirements imposed by such vacuum chambers and to make diffusion welding more economical.

The research was done under the auspices of a commission of the Federal Defense Ministry.

Translated for the National Aeronautics and Space Administration under contract No. NASW-2485 by Techtran Corporation, P. O. Box 729, Glen Burnie, Maryland, 21061, translator: Thomas Appich.